INVESTIGATION

OF THE

RELATIVE DURABILITY OF ILLINOIS BUILDING STONE,

BY

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THESIS

For the Degree of Bachelor of Science

in Civil Engineering.

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UNIVERSITY OF ILLINOIS.

1895.

RELATIVE DURABILITY

OF SOME

ILLINOIS BUILDING STONES.

One of the chief advantages of masonry construction is its durability, and therefore the most durable building stones are the most serviceable. It is difficult to determine the probable durability of building stones, owing to the following reasons; (1) The destructive agencies can not be exactly reproduced artificially. (2) The relative values of the different methods of testing are not definitely known. (3) Some good building stones have been in use for so short a time that it is impossible to determine their durability except by artificial methods.

METHODS OF DETERMINING DURABILITY.

There are two general methods of determining the durability of building stones. They are the natural and the artificial.

NATURAL METHODS.

There are two natural methods of determining durability: the examination of the outcrop at the quarry, and the inspection of the stone in an old building. The first of these is applicable only when the rock outcrops, which is not the case with all building stones. The second is not applicable if the particular stone has been in use but a short time. Either of these methods give valuable information, and all of the data obtained by them is important.

ARTIFICIAL METHODS.

The older but less satisfactory artificial methods are determining (1) the resistance to crushing, (2) the resistance to expansion of frost, (3) the resistance to the crystallization in the pores of the stone of a sulphate of soda solution, (4) the relative weights, (5) the solubility in acids, and (6) the ease of dressing.

The compression test is included in the artificial methods of testing durability, because a stone that is strong is usually also durable; but the test is not of very great importance. The freezing test is the most important of all of the artificial methods. The chief cause of failure in masonry construction is due to the action of frost. The sulphate of soda test has the same general effect on the dtones as the freezing test and is sometimes substituted for it. The specific gravity test is chiefly valuable as showing the weight of a unit volume of each stone. The test is not especially important. The acid test is of some importance, since it determines the probable effect of the acids in the atmosphere and in the rain. Ease of dressing determines the power of a stone to withstand shocks. This test is also important, since stone that can not be dressed readily and at a reasonable cost is not very serviceable for ashlar work.

OBJECT OF THIS INVESTIGATION.

The purpose of this work was to determine the relative durability of some of the building stones of East Central Illinois.

So far as the writer knows, no experiments have been made to determine the durability of stones used in this locality. Specimens of the following six varieties of stone were carried through a series of tests in which the destructive agencies of masonry construction were approached as nearly as possible by artificial means.

Berea Sandstone	Portland Sandstone
Bedford Limestone	Williamsport Sandstone
Kankakee Limestone	Lake Superior Sandstone

Much to his surprise and regret, the writer was unable to obtain samples of the Joliet Limestone. The Bedford Limestone, on account of its high rank as a durable building stone, was included in these tests for the sake of comparisons. Except the Lake Superior Sandstone, the others are in general use in this locality.

<u>Description of the Different Varieties</u>. Blue Berea Sandstone is a compact stone, homogeneous in structure, and greyish-blue in color. It is quarried by the Cleveland Stone Company at Cleveland, Ohio, and is used extensively as a building stone in Ohio, Indiana, and Illinois.

Bedford Limestone is light grey in color, and homogeneous in structure. The particles are well cemented together, and the stone is very tough and durable. It is quarried at Bedford, Indiana, and Illinois.

Kankakee Limestone is a very hard and compact stone, nearly white in color, although the traces of iron are seen in some specimens. It is very difficult to cut. It is quarried at Kankakee, Illinois, and has quite an extended use in Illinois and the adjoining States for range and rough rubble, rip-rap, and retaining walls.

Portland Sandstone is light grey in color and contains a large per cent of the sands of the various rocks, quartz being a prominent constituent. It is quarried at Obedee, Indiana, twenty-five miles southeast of Danville, Illinois. It has only recently come into general use as a building stone. The particles are not well cemented together, and a quick, hard blow will crack the stone very readily.

Williamsport Sandstone is dull blue in color, and contains a large per cent of clay. It belongs to the argillaceous sandstones, is quarried at Williamsport, Indiana, and is almost identical with the Independence sandstone, the two being outcrops from the same strata. It has an extended use in Western Indiana and the adjoining portion of Illinois.

Lake Superior Sandstone is dark red in color, and like the Portland stone the particles are not well cemented together, consequently the rock crumbles easily. It is quarried in Michigan, near Lake Superior.

COMPRESSIVE STRENGTH.

Preparation of Specimens. Cubes of each variety were prepared on a grinding machine. The number from each was intended to be four, but the only block of Portland stone available was found to be so injured that but three specimens could be obtained from it.

Description of the Grinding Machine upon which the Cubes were Prepared. The machine consists of a disc of iron, two feet in diameter and eight inches thick. This is set in a frame consisting of four vertical rods A' Fig. 2, Page 5, and three spiders, IG, Fig. 1, in horizontal planes. The disc was set on the middle spider L', as shown at O', Fig. 2. A vertical rod H', Fig. 2, pierces the center of the disc at H, Fig. 1, and passes through the spider at the intersection of the cross-bars at H, Fig. 1 and N', Fig. 2. It is pivoted at T', Fig. 2, in the lower spider, and turns about a vertical axis. The pulley in Fig. 2 is the belt attachment. The spider G'I' in Fig. 2 is fastened to N', Fig. 2 so that a quarter of an inch is left between the disc and the lower edge of the spider. This space is for the passage of sand and water with which the disc is kept covered. The bars of the spider G'I' are one-half inch thick and project vertically from the disc face two and one-half inches. The angle a Fig. 1, is a right angle to aid in the finishing of the cubes. Below and around the disc is a pan made of zinc to collect the drip, and on one side is a spout to carry away the water. The space between the pan and the edge of the disc is about one-half inch.

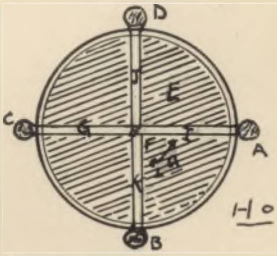


Fig 1
HOR. PROJ.

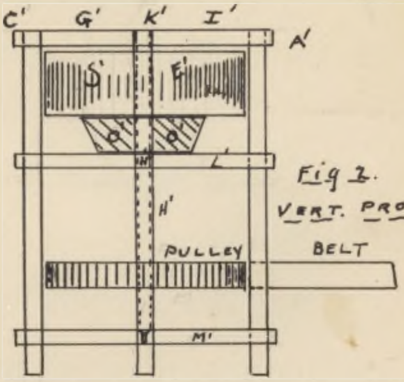


Fig 2.
VERT. PROJ.

Process of Grinding the Cubes. The rough stone is held against one leg of the top spider and on the disc while it is covered with wet sand, until a smooth face is finished. Then this face is held against the spider leg until another face is finished at right angles to the first. This proceeds until a cube is finished. The disc makes about forty revolutions per minute and several cubes can be handled at the same time.

The size of the cubes ranges from 1.3" to 2.1", the intention being to eliminate any error in the calculation of the ultimate unit stress, even if General Gilmore's law that the ultimate unit stress varies with the cube root of the first power of the edge of the cube, be true. The calculation of the ultimate unit stress for the data in Table I was made by dividing the breaking load by the area of one face of the cube.

<u>Cushions</u>. An exhaustive research was made to determine the best materials for cushions, in order that the conditions may be the same in each. The writer found from a series of tests of the same variety of stone, that copper, lead, and leather gave uniform results; but that for soft stones these cushions reduced the ultimate compressive unit stress, while a harder cushion did not.

<u>Crushing the Cubes</u>. After the cubes had been prepared they were left in a warm room for seven days. They were then carefully brushed, and the measurements of their edges were taken with a pair of vernier calipers. The maximum error was one hundredth of an inch. The pressure was applied perpendicular to the bed, with a Riehlé Bros.'s testing machine, the cushions being self-adjusting parallel steel-plates.

TABLE I.

TESTS OF CRUSHING STRENGTH.

The pressure was applied at the rate of 4000 lbs. per minute.

Ref. No.	Variety	Lenght of Edge in inches	Crushing Strength in lbs. per sq.in.	Relative Rank	Remarks.
1	Berea	1.65			
2	"	1.85			
3	"	1.90			
4	"	1.87	6120	3	
1	Bedford	2.00			
2	"	2.00			
3	"	2.00			
4	"	2.00	8500	2	
1	Kankakee	1.65 -	- - - -	- - -	Cracked
2	"	1.96			(at 8000
3	"	1.88			(lbs. per
4	"	1.94	10800	1	(sq. in.
1	Portland	1.20			
2	"	1.50			
3	"	1.50	4330	5	
1	Williamsport	1.60			Low ulti-
2	"	1.40			(mate unit
3	"	1.58			(stress,
4	"	1.85	4160	6	(discarded.
1	L. Superior	2.10			
2	"	2.15			
3	"	2.00			
4	"	2.10	4500	4	

Conclusions. These tests show that the Kankakee stone is the strongest, the Bedford and Berea being 2000 and 4000 lbs. lower respectively, while the Williamsport is only 40 per cent as strong. But actual observation shows that the Williamsport stone is sufficiently strong and durable for any masonry work, so this test is of little value except as showing the relative strengths.

FREEZING TEST.

The object of this test is to determine the relative effect of water freezing in the pores of the different stones.

Preparation of Specimens. The specimens were cubes prepared as for the compressive test, one cube of each variety being used. When the cubes were dried to constant weight, they were brushed thoroughly to remove all loose particles, and then weighed.

Description of Experiment. The cubes were soaked in distilled water for twelve hours and then frozen for twelve hours at an average temperature of seven degrees Fahr. This was continued for fourteen days, when the cubes were again dried to constant weight, brushed as before, and weighed. From the weights before and after the freezing, the loss of weight in each specimen was calculated. The results are shown in Table II.

TABLE II.

FREEZING TEST.

Ref. No.	Variety	Weight before, in Grams	Weight after, in Grams	Loss of weight		Relative Loss	Relative Rank
				Grams	%		
1	Berea	200.5	199.1	1.4	0.70	1.00	1
2	Bedford	156.5	152.1	4.4	2.81	4.01	3
3	Kankakee*	147.2	146.0	1.2	0.82	1.71	2
4	Portland	139.0	133.8	5.2	3.74	5.34	5
5	Williamspt	205.1	199.3	5.8	2.88	4.11	4
6	L.Superior	255.2	147.5	7.7	4.95	7.07	6

* The specimen of the Kankakee limestone cracked in several places, probably due to microscopic cracks in the stone before the freezing.

Conclusions. From Table II it will be seen that the Berea sandstone was least affected, Lake Superior most. This test gives the rank of the stones with respect to weathering, which is certainly the most powerful of all destructive agencies, and where dimension stone is not required this rank determines their value as building stones.

SULPHATE OF SODA TEST.

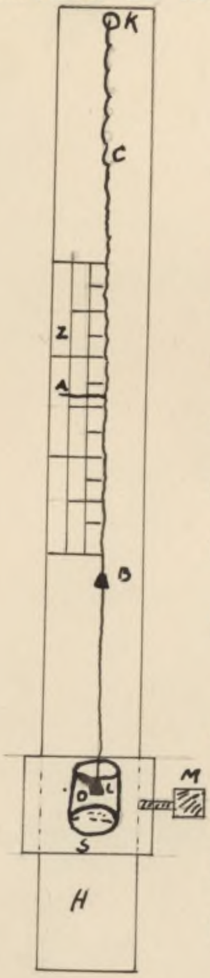
The object of this test is to determine the effect of the formation of crystals of sulphate of soda in the pores of the different stones. The general effect is similar to that of water freezing in the pores. The specimens were rough pieces with good stable faces, and were well brushed and dried to constant weight before the test. A kettle was half filled with water and enough sulphate of soda was added to make a saturated solution. To be sure that this was obtained, the salt was added until there was some left in the kettle undissolved while the water was boiling. The specimens were dropped into the solution and it was allowed to boil for thirty minutes. The specimens were left in the solution for ten hours, when they were suspended by strings in a dark room for twelve hours. This process was repeated fourteen times. At the end of fourteen days the specimens were taken out, washed, brushed, and dried to constant weight, and then weighed. The results are given in Table III.

TABLE III.

SULPHATE OF SODA TEST.

Ref. No.	Variety	Weight before in Grams	Weight after in Grams	Loss of Weight		Relative Loss	Relative Rank
				Grams	%		
1	Berea	137.5	130.8	1.7	1.29	1.22	2
2	Bedford	169.7	167.9	1.8	1.06	1.00	1
3	Kankakee	88.8	87.3	1.5	1.68	1.60	4
4	Portland	139.8	136.7	3.1	2.21	2.20	5
5	Williamspt	169.7	167.9	1.8	1.60	1.53	3
6	L.Superior	121.6	118.3	3.3	2.70	2.13	6

Conclusions. A comparison of the results of the freezing and sulphate of soda tests shows that the relative losses are not the same. The difference is sufficient to give a different rank in the two tests. The conclusions to be drawn from the results are that the sulphate of soda is not as active a destructive agency as the frost, and that the relative durability determined by this method is not as reliable as that determined by the freezing test.



SPECIFIC GRAVITY.

The instrument for finding the specific gravity is shown in Fig. 3. K is a ring in which is fastened a wire C with a coiled spring. Z is a graduation on a mirror. A is a pointer fixed to the wire C. B is a cup fixed to the wire C. L is another cup attached to C. O is a vessel containing water. M is a set screw for adjusting the stand S on the board H to place L below the water surface and above the bottom of the glass.

To use the instrument, the cup L is adjusted so that it is near the top of the water O, and the reading of A on Z is taken. A small piece of the stone is placed in B and a second reading is taken. If L touches the bottom, use a smaller piece of stone or lower the stand S. When the second reading is taken, remove the stone and place it in the cup L and then take a third reading. The specific gravity is given by the formula

$$S.g. = \frac{R_2 - R_1}{R_2 - R_3}$$

in which R_1 is the first reading, R_2 the second reading, R_3 the third reading. The results obtained by this instrument are accurate within five per cent. The specific gravity as determined by this instrument is shown in Table IV.

TABLE IV.

SPECIFIC GRAVITY.

Ref. No.	Variety	Specific Gravity	Rank	Remarks
1	Berea	2.40	3	
2	Bedford	2.40	3	
3	Kankakee	2.35	6	
4	Portland	2.74	1	
5	Williamsport	2.40	3	
6	L. Superior	2.50	2	

Conclusions. This table shows that the variation of the specific gravities is so small that the test is of little importance.

ACID TEST.

This test is to determine the effect of the atmosphere of a large city, where coal is used for fuel.

Description of the Test. One specimen of each variety of stone was immersed in a mixture of one part hydrochloric acid and ninety-nine parts distilled water. After seven days the specimens were removed, and the relative amount of residue was estimated by eye, and the rank was assigned accordingly.

TABLE V.

ACID TEST.

Ref. No.	Variety	Relative Rank	Remarks
1	Berea	1	
2	Bedford	1	
3	Kankakee	3	
4	Portland	4	
5	Williamsport	5	
6	Lake Superior	6	

Conclusions. The table shows that the Berea and Bedford stones are least affected, while the Kankakee is third. This leads to the general conclusion that the stones which best withstand the freezing and sulphate of soda tests, are also least affected by the acid test.

EASE OF CUTTING.

How Determined. The classification of the stones with regard to ease of cutting was made by the writer from observing workmen dressing the stones. He was also aided by personal use of a chisel.

Berea sandstone is homogeneous in structure and is the most easily dressed. It works well with an ordinary chisel and judicious handling of the bush hammer will not crack the stone.

Bedford limestone is harder and tougher than the Berea, and can not be cut quite so easily. The particles are so well cemented that there is no danger of failure from careful bush hammering.

Kankakee limestone is very hard and tough, and for this reason is rarely used in cut-stone or dimension-stone construction.

Portland sandstone is very soft. It is easily cut with an ordinary chisel, but cracks when struck quick, sharp blows. The faces are very easily deadened.

Williamsport sandstone is soft, compact, and contains a large per cent of clay. It is readily cut by chisels and is broken by sharp blows.

Lake Superior sandstone is a somewhat porous stone and the cementing material does not hold the grains together well.

It absorbs a large per cent of water and is easily cut by the chisel. Bush hammering should not be allowed.

TABLE VI.

EASE OF CUTTING.

Ref. No.	Variety	Rank	Remarks
1	Berea	1	
2	Bedford	2	
3	Kankakee	6	
4	Portland	4	
5	Williamsport	3	
6	Lake Superior	5	

SUMMARY.

This classification is the system that is used in most relative tests. The sum of the ranks of each stone in the tests, determines its final rank.

TABLE VII.

SUMMARY OF RANKS.

Ref. No.	Variety	Compressive Strength	Sulphate of Soda Test	Freezing Test	Acid Test	Specif. Gravity	Ease of Cutting	Final Rank
1	Berea	3	2	1	3	1	1	1
2	Bedford	2	1	3	3	1	2	2
3	Kankakee	1	4	2	6	3	6	3
4	Portland	5	5	5	1	4	4	4
5	Williamsport	6	3	4	3	5	3	4
6	Lake Superior	4	6	6	2	6	5	6

Conclusions. The writer is of the opinion that it is not necessary to include all of these tests to determine the rank of the stones. The classification, however, should be under two heads.

First. Ashlar and dimension-stone work, in which the freezing test and ease of cutting are taken as of equal importance;

Second. All other forms of masonry constructions, in which the freezing test alone determines the rank.

TABLE VIII.

ASHLAR AND DIMENSION-STONE WORK.

Ref. No.	Variety	Freezing Test Rank	Ease of Cutting Rank	Relative Rank
1	Berea	1	1	1
2	Bedford	3	2	2
3	Kankakee	2	6	4
4	Portland	5	4	5
5	Williamsport	4	3	3
6	Lake Superior	6	5	6

TABLE IX.

OTHER FORMS OF MASONRY CONSTRUCTION.

Ref. No.	Variety	Freezing Test Rank	Rank
1	Berea	1	1
2	Bedford	3	3
3	Kankakee	2	2
4	Portland	5	5
5	Williamsport	4	4
6	Lake Superior	6	6

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